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A PAL/YUV digital system for 625-line international connections

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A PAL/YUV DIGITAL SYSTEM FOR 625-LINE INTERNATIONAL CONNECTIONS

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Summary

The system described is an efficient Y, U, V based digital coding system which could be used for the distribution of colour television signals. The system samples Y at $2\ f_{sc}$ *and (U + V) and (U − V) on alternate lines at* f_{sc}. *These signals are derived using comb-filters in order to reduce high frequency luminance alias and vertical chrominance cross-talk effects. Similar comb-filters can be used to convert between digital* Y_s*,(U+V/U−V) and PAL. It is shown that the PAL to* Y_s*, (U+V/U−V) to PAL process is almost completely reversible and this has been confirmed by experiment.*

Issued under the authority of

Monteath

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A PAL/*YUV* DIGITAL SYSTEM FOR 625-LINE INTERNATIONAL CONNECTIONS

M. Weston, B.A.

1. Introduction

At the present time all International circuits used, in Europe, for programme exchange, carry analogue signals according to the colour system adopted by the country of origin, that is either SECAM or PAL. If transcoding is necessary, it is carried out by the recipient country. It is, however, anticipated that such circuits will carry digital signals and it is felt, particularly within the EBU, that these circuits should carry signals which, if possible, eliminate the need for transcoding.

Signals based on the luminance and colour-difference components (*YUV*) are favoured, since they may be coded into either SECAM or PAL as required. The use of *YUV* would in principle provide an ideal solution if the signals used in all the studios were also of the *YUV* form; clearly, transcoding would be eliminated. However, all PAL countries originate in PAL and are likely to continue doing so indefinitely.

Even so, SECAM to PAL transcoding could be eliminated if *YUV* signals were used on the International circuits by providing appropriate coding and/or decoding equipment at the input and output points. If, however, the coding and decoding arrangements used were based on current techniques, significant loss of picture quality could occur, particularly for transmissions from one PAL country to another.

The system to be described enables PAL signals to be transcoded to a *YUV* form and then transcoded back to PAL with negligible loss. At the same time the *YUV* so produced can be coded into SECAM to produce good quality SECAM pictures. Further, the form of *YUV* generated by the system is broadly similar to that suggested by *YUV* proponents for use in digital networks.

2. Technical description

The system[1] concept is based on digitally processing either a PAL signal, or a *YUV* separate-component signal, to produce a luminance signal Y_s sampled at $2 \times f_{sc}$* and a chrominance signal, sampled at f_{sc}, consisting nominally of $(U+V)$ and $(U-V)$ on alternate lines.

In this Report the derivation of the two constituent signals from PAL, and their re-combination to provide a PAL signal, is preceded by a description of their characteristics, together with an outline of how they may be obtained from, and processed to provide, *YUV* signals of the conventional form.

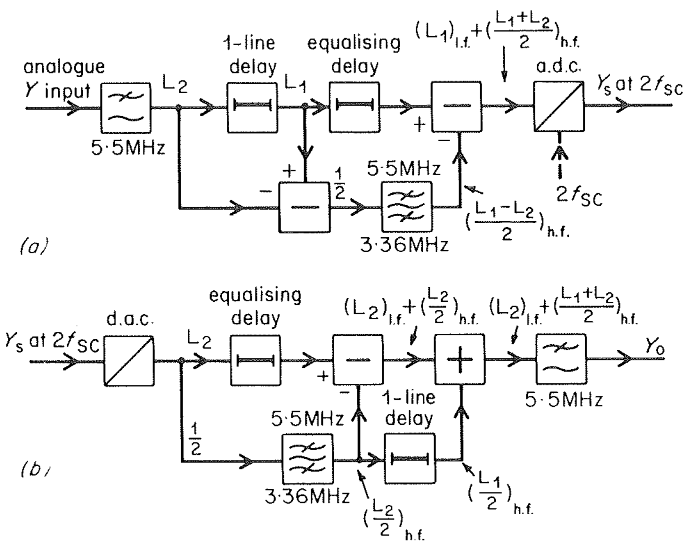

Fig. 1 - 2 f_{sc} sampling

(*a*) input filter and a.d.c. (*b*) d.a.c. and output filter

L_1 and L_2 represent signals from the previous and current lines

2.1. The luminance component (Y_s)

Y_s consists of a conventional luminance signal sampled at 2 f_{sc} (≃8·86 MHz), that is at a frequency less than twice the highest video frequency (5·5 MHz for the PAL system). However, in order to minimise the generation of in-band alias components in the band 3·36 to 5·5 MHz, the input luminance signal is comb-filtered prior to sampling.[2]

The comb-filter illustrated in Fig. 1(*a*) removes harmonics of half the line frequency by averaging the input and output of a line delay, the averaging being restricted to the band 3·36 to 5·5 MHz by means of a band-pass filter. The response/frequency characteristic of the comb-filter, combined with that of a 5·5 MHz low-pass filter, is shown in Fig. 2(*a*), where the pitch of the comb-filter 'teeth' has been exaggerated for clarity. Fig. 2(*b*) illustrates how the alias components generated by sampling at 2 f_{sc} fall mainly in the gaps created by the input comb-filter.

In order to provide, from Y_s, a luminance signal Y_o that may be substituted for a conventional Y signal, further filtering is necessary. Most of the alias components remaining in Y_s may be removed by a second filter, of the form shown in Fig. 1(*b*). This filter also removes odd harmonics of half the line frequency in the 3·36 to 5·5 MHz region, leaving the residual alias components shown in Fig. 2(*d*).

The filters of Fig. 1(*a*) and Fig. 1(*b*) are not identical. The first delays low-frequencies (<3·36 MHz) relative to the high-frequency components. However, the converse occurs in the second filter and this ensures that, after passage through both filters, the delay for all frequencies is

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* f_{sc} is the PAL subcarrier frequency.

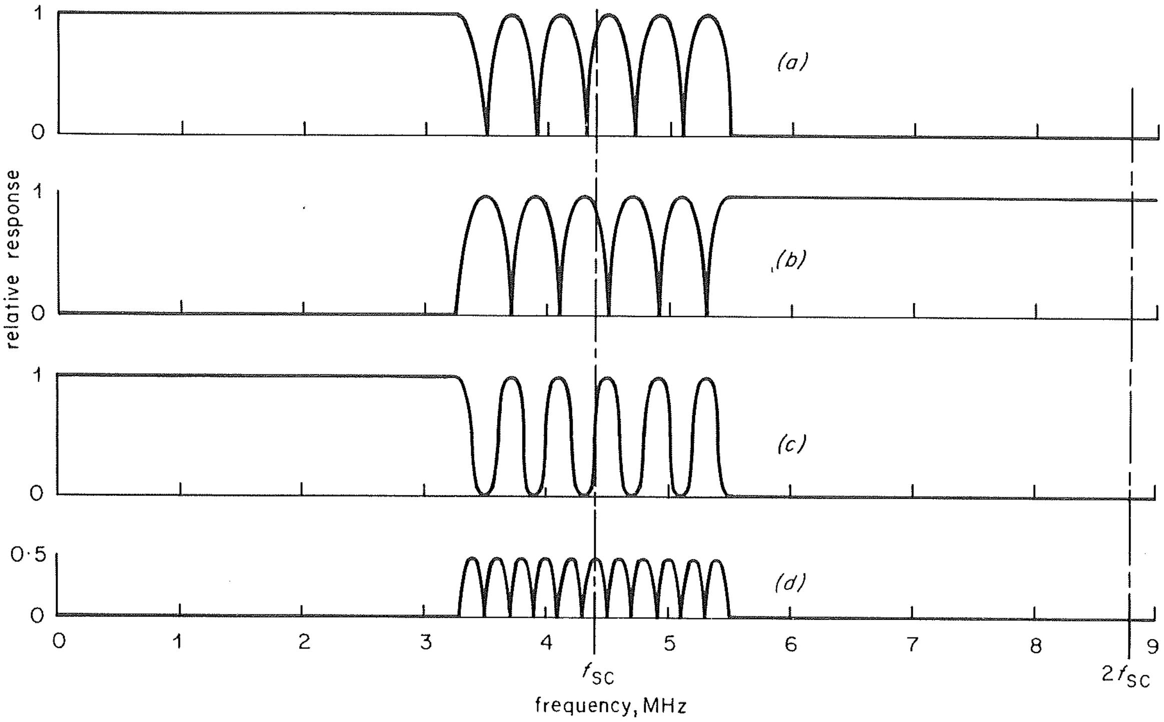

Fig. 2 - Effect of luminance comb-filters
(*a*) filtered luminance before $2f_{sc}$ sampling (*b*) alias from $2f_{sc}$ sampling
(*c*) luminance after output filter (*d*) residual alias after output filter

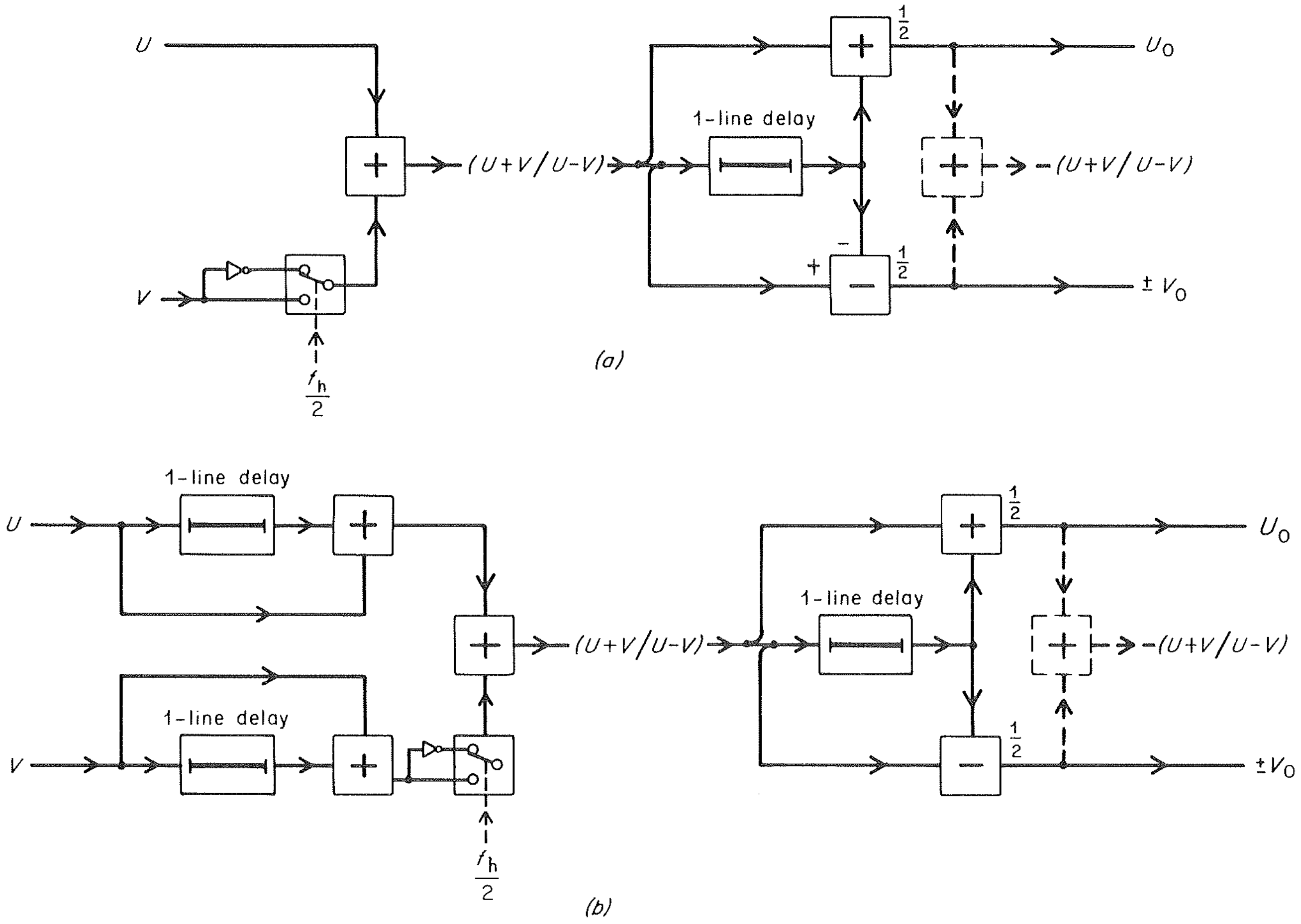

Fig. 3
(*a*) simple combination and separation of *U* and *V* (*b*) combination and separation of pre-filtered *U* and *V*

constant. Fig. 2(c) shows the combined effect of the two filters, and indicates that the output of the second filter, Y_0, is characterised by a loss of high-frequency diagonal information.

It is relevant to point out that as the simple filters described use only one-line delays, they do not provide ideal characteristics; the teeth shown in Fig. 2(c) are not square in shape and permit the residual components shown in Fig. 2(d) to appear in Y_0. More complex filters using multiple line delays would substantially reduce the level of the unwanted components.

2.2. The chrominance component ($U+V/U-V$)

As already indicated this signal may be obtained from conventional U and V signals by deriving their sum ($U+V$) during one television line, and their difference ($U-V$) during the succeeding line; the two derived signals then alternate line by line. By limiting the bandwidths of U and V to 2·2 MHz, ($U+V/U-V$) may be digitised using a sampling frequency of f_{sc}.

Fig. 3(a) illustrates the generation of ($U+V/U-V$) and also shows how this signal may be used to provide signals U_0 and V_0 similar to the input signals U and V; the processes of sampling, digital coding and digital decoding are not shown.

However, filtering using a one-line delay causes the vertical resolution provided by U_0 and V_0 to be reduced. Fig. 4(a) shows the effect upon U_0 of a step change in U from one television line to the next, e.g. as could occur at a sharp horizontal coloured edge in the picture. It will be seen that, in addition to softening the U_0 transition, the arrangement produces a large cross-talk pulse in V_0. Similar results are obtained for a step change in V. The polarities of these cross-talk pulses alternate for the same line in successive pictures, which can cause flicker at sharp horizontal picture boundaries involving saturated colours (e.g. those produced by horizontal colour bars).

The unwanted cross-talk effects can be mitigated by comb-filtering the input U and V signals before combining them to form ($U+V/U-V$). The arrangement shown in Fig. 3(b) uses comb-filters that average the U and V input signals on successive lines so as to produce components of ($U+V/U-V$) with the spectra shown in Figs. 5(a) and 5(b). It will be seen that the maxima in the spectrum of the $\pm V$ component are offset from those of the U component by half the line frequency; this is due to the alternation of the V signal polarity prior to its combination with the U com-

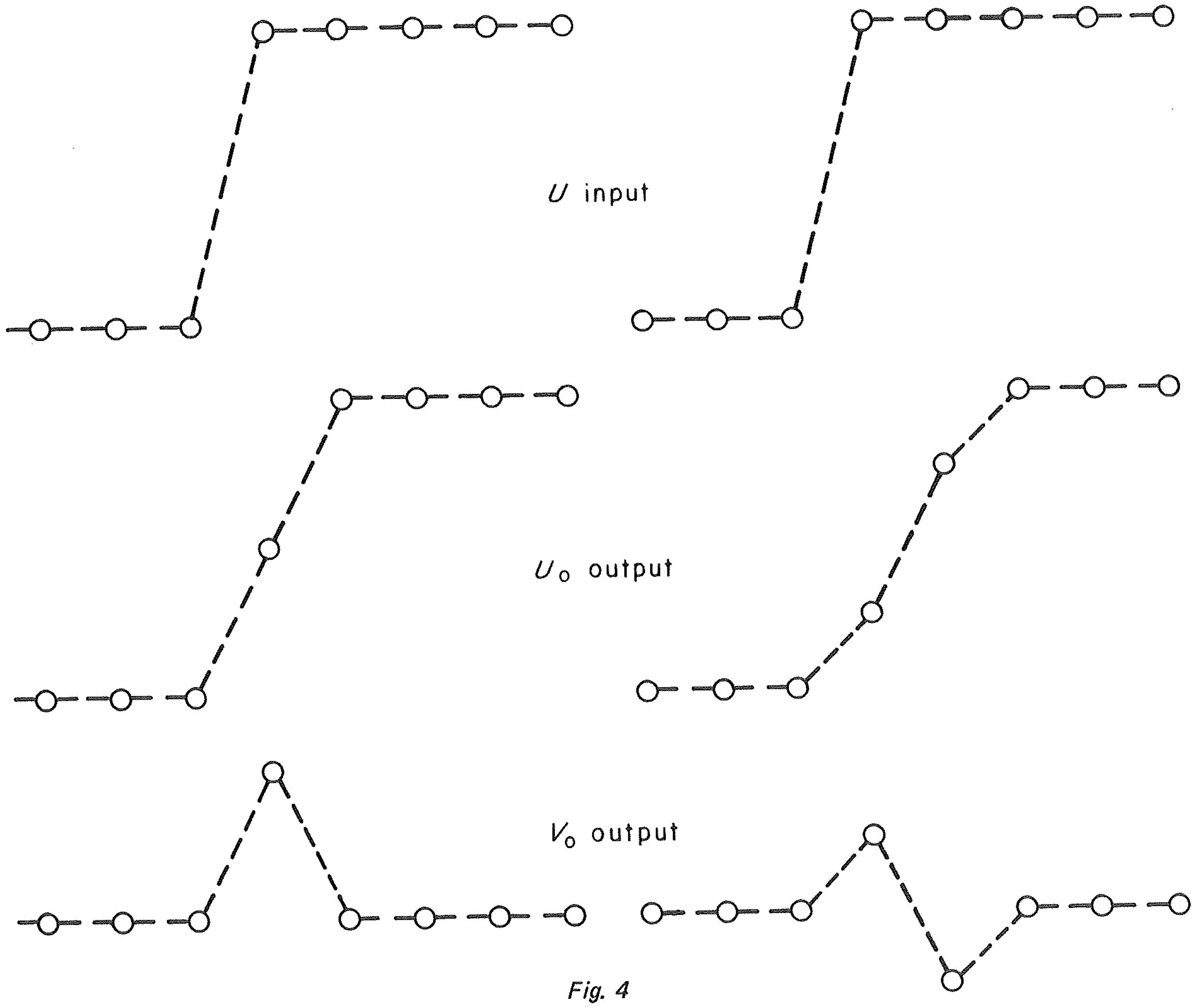

Fig. 4

(a) Vertical step response of Fig. 3(a) (b) Vertical step response of Fig. 3(b)

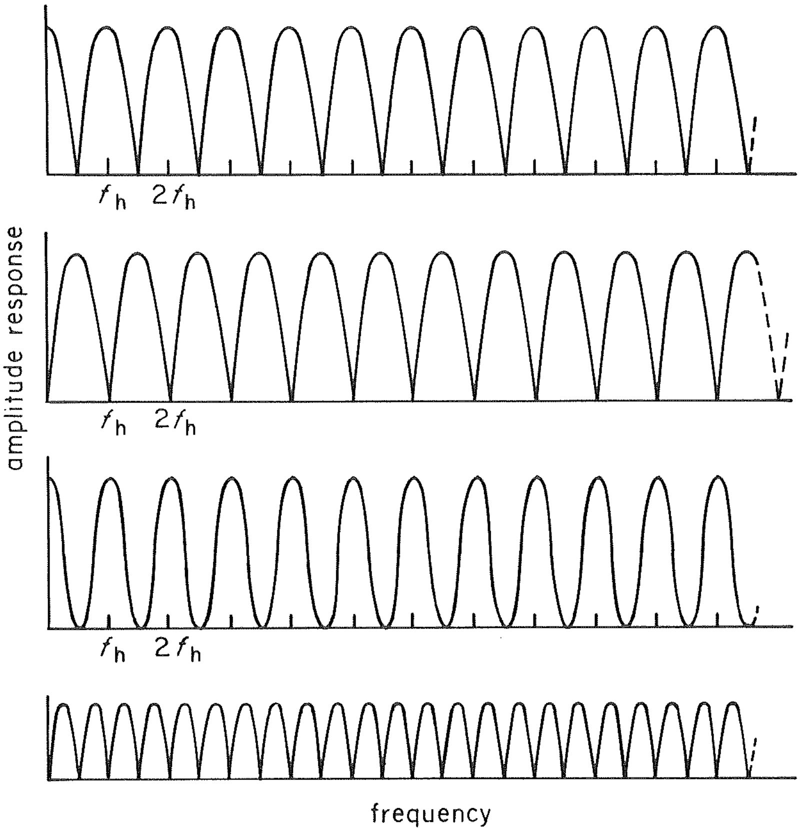

Fig. 5 - Effect of chrominance comb-filter
(*a*) comb-filtered U component of $(U+V/U-V)$
(*b*) comb-filtered $\pm V$ component of $(U+V/U-V)$
(*c*) separated U_0 output
(*d*) $\pm V$ component on U_0 output

ponent. Thus, in $(U+V/U-V)$ the main information carried by the V component is represented by frequencies at which the energy of the U component is zero, and vice-versa.

The effect of these input comb-filters is illustrated in Fig. 5(*c*) where it will be seen that the spectrum of U_0 contains most of the information provided by U. However, some residual cross-talk from V into U_0 also occurs; the spectrum of the residual V cross-talk is shown in Fig. 5(*d*). Similar results are obtained for the output $\pm V_0$.

Fig. 4(*b*) illustrates how the effect of a step change in U from one line to the next is modified using the arrangement of Fig. 3(*b*). The cross-talk now has different characteristics; the single pulse of Fig. 4(*a*) is replaced by two smaller pulses of opposite polarities.

Clearly the vertical resolution provided by $(U+V/U-V)$ is reduced, compared to that potentially provided by U and V. Further, some cross-talk is present in both the U_0 and $\pm V_0$ outputs. However, as in the case of the luminance signal Y_0, the use of more complex filters could reduce this cross-talk.

Finally, it should be noted that $(U+V/U-V)$ may be re-formed from U_0 and $\pm V_0$ by adding them together, as is shown (dotted) in Figs. 3(*a*) and 3(*b*).

2.3. Processing PAL to provide Y_s and $(U+V/U-V)$

The preceding sections have outlined the characteristics of Y_s and $(U+V/U-V)$ and described how they may be derived from Y, U and V.

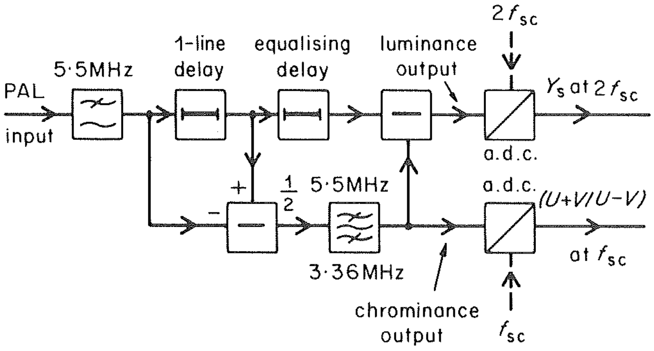

Fig. 6 - PAL to Y_s, $(U+V/U-V)$ process — block diagram

The signal processing required to provide Y_s and $(U+V/U-V)$ from PAL is shown in Fig. 6, and basically consists of a comb-filter very similar to that illustrated in Fig. 1(*a*), but having an additional output from the band-pass section of the comb filter, together with suitable sampling arrangements associated with analogue/digital conversion.

2.3.1. Luminance (Y_s) output

As with its derivation from Y, shown in Fig. 1(*a*), Y_s is obtained by first removing the odd harmonics of half the line frequency contained in the input PAL signal. However this process does not remove the chrominance components; they are centred upon odd harmonics of quarter the line frequency and the comb-filter attenuates them by only 3 dB.

The remaining chrominance components may, however, be rejected by sampling the filter output at instants when the chrominance waveform is passing through zero. This is possible because the action of the one-line delay in the filter causes the quadrature modulated U and V components to be brought into phase or into anti-phase with one another.

The action of the one-line delay is illustrated in Figs. 7(a), 7(b), 7(d) and 7(e). These show that the U components of the 'previous' line (the line emerging from the one-line delay) leads the U component of the 'current' line (that entering the delay) by 90°, and that the resultant is a U component attenuated by 3 dB and effectively phase advanced by 45° with respect to the current line. Similarly the V component of the previous line lags that of the current line by 90°, so that the resultant V component is, as in the case of U, attenuated by 3 dB, but is phase retarded by 45° with respect to the current line. Thus the chrominance signals emerging from the luminance output of the filter may be rejected by sampling at $2f_{sc}$ with a suitable phase relationship to the input chrominance signal. Clearly this process relies upon identical chrominance signals occurring during successive lines (i.e. in picture areas of plain colour). When changes in the chrominance signal occur from one line to the next (e.g. due to vertical colour detail) some chrominance breakthrough will occur into the luminance signal Y_s.

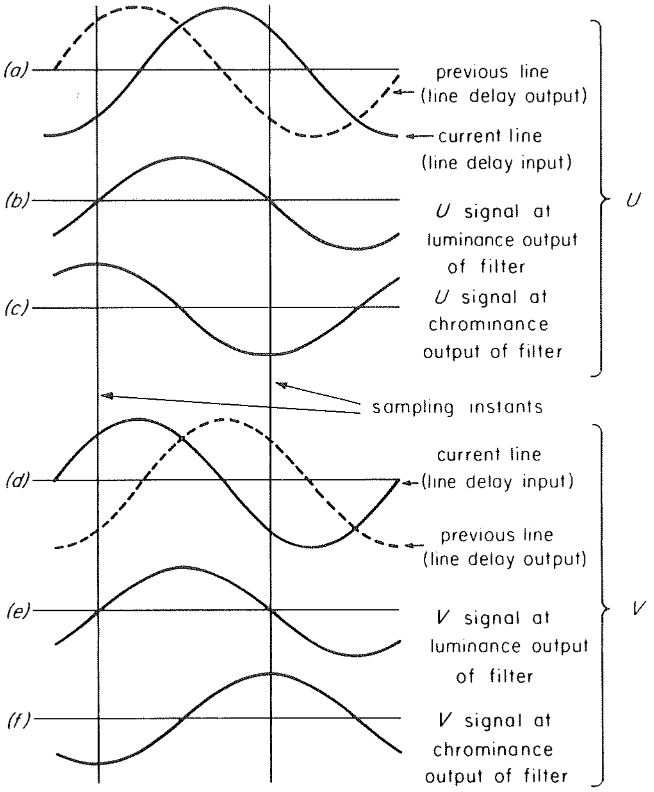

Fig. 7 - PAL to Y_s, $(U+V/U-V)$ process — waveforms

2.3.2. Chrominance $(U+V/U-V)$ output

The chrominance signal output is the difference between the chrominance signals from successive lines. Figs. 7(c) and 7(f) show that, in this case, the resultant chrominance signals corresponding to U and V are phase-shifted by 90° with respect to those presented at the luminance output and their waveforms peak at the instants at which the latter are passing through zero.

Sampling the chrominance at $2f_{sc}$ would give the outputs:—

$(U+V)$		$-(U+V)$		$(U+V)$		$-(U+V)$		$(U+V)$	on line n
	$(U-V)$		$-(U-V)$		$(U-V)$		$-(U-V)$		on line n+1
$-(U+V)$		$(U+V)$		$-(U+V)$		$(U+V)$		$-(U+V)$	on line n+2
	$-(U-V)$		$(U-V)$		$-(U-V)$		$(U-V)$		etc.

Since the signals have been band-pass filtered the resulting chrominance may be sampled at f_{sc} to give:—

$(U+V)$				$(U+V)$				$(U+V)$	on line n
	$(U-V)$				$(U-V)$				on line n+1
		$(U+V)$				$(U+V)$			on line n+2
			$(U-V)$				$(U-V)$		etc.

The decoder thus produces a $(U+V/U-V)$ signal similar to that produced by the arrangement illustrated in Fig. 3(b).

As in all PAL decoding processes some h.f. luminance components will be interpreted as chrominance. In this case the comb-filter prevents luminance components at harmonics of the line frequency reaching the chrominance output. These components are the most likely to occur but do not give rise to the most objectionable cross-colour patterns. The most visible patterns are produced by luminance components with frequencies near odd harmonics of quarter the line frequency (these are demodulated as coarse patterns). The comb-filter attenuates these components by the same amount (3 dB) as the true chrominance components.

Thus the overall visibility of cross colour is about the same as with conventional decoders, although for some pictures (e.g. Test-card resolution bars) the situation may be improved; odd harmonics of half the line frequency are enhanced by 3 dB but these components are perhaps less likely to occur and do not give very visible patterns.

2.4. Coding Y_s and $(U+V/U-V)$ to PAL

Y_s and $(U+V/U-V)$ could be converted to Y_o, U_o

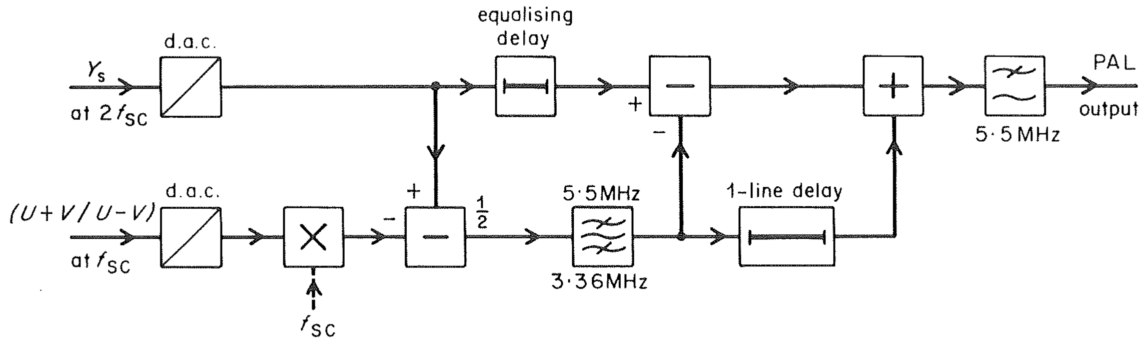

Fig. 8 - Y_s, (U+V/U−V) to PAL process — block diagram

and V_0 which could then be coded to PAL in a conventional manner. Fig. 8, however, shows a comb-filter which carries out the complete operation; it accepts Y_s sampled at $2f_{sc}$ and the combined chrominance sampled at f_{sc}, and produces a PAL coded signal.

2.4.1. Luminance input

The comb-filter of Fig. 8 treats the luminance input in exactly the same way as the output filter in Fig. 1(*b*), attenuating alias components at or near odd harmonics of half the line frequency.

2.4.2. Chrominance input

The chrominance signal $(U+V/U-V)$ first modulates a subcarrier wave and the resulting signal is passed to the comb-filter. The action of the line-delay in the filter is to advance the phase of the U component by 45° and to retard the $\pm V$ component by 45°, thus generating separate components modulated onto quadrature carriers. The action of the line-delay is similar to that explained in Section 2.3.2.

2.5. Coding PAL from Y_s and $(U+V/U-V)$ derived from PAL

Most of the impairments introduced by deriving Y_s and $(U+V/U-V)$ from PAL are cancelled by recoding to PAL.

Fig. 9 shows that, although the processes involve filters which reduce the diagonal luminance resolution and vertical chrominance resolution of Y_s and $(U+V/U-V)$, no information is lost; all information removed from Y_s is contained in $(U+V/U-V)$, and vice versa. The Y_s, $(U+V/U-V)$ to PAL coder recombines the signals to regenerate the original PAL signal merely delayed by one line period.

Decoding and recoding can thus, in principle, be performed many times without the impairments building up to objectionable levels.

This is only strictly true if the comb-filters use perfect band-pass filters with an infinite rate of cut; the response of such a filter is unity in-band and zero out of band. In practice there will be a region on the band edge where the response is neither unity nor zero. At these frequencies the signals will not recombine perfectly.

2.6. Digital instrumentation

Fig. 10 shows how the comb-filtering and other operations of Figs. 1, 6 and 8 may be performed digitally.

The analogue input is first converted into an 8 bit digital signal at a sampling rate of $4f_{sc}$ and, for PAL inputs, the sampling instants are adjusted to be 45°, 135°, 225° and 315° with respect to the U subcarrier phase by a digital burst-phase comparator which controls the exact frequency of a voltage-controlled $4f_{sc}$ clock generator.

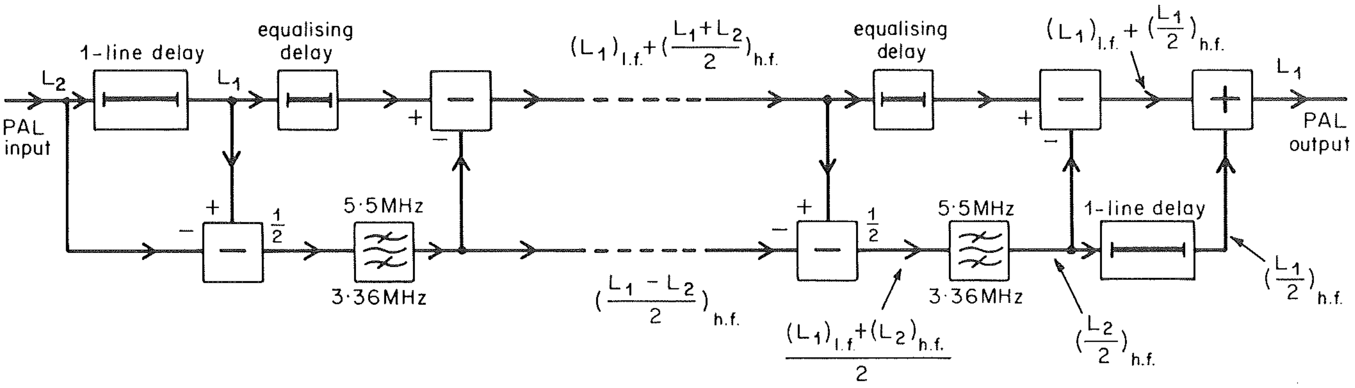

Fig. 9 - PAL to Y_s, (U+V/U−V) to PAL

L_1 and L_2 represent signals from the previous and correct lines

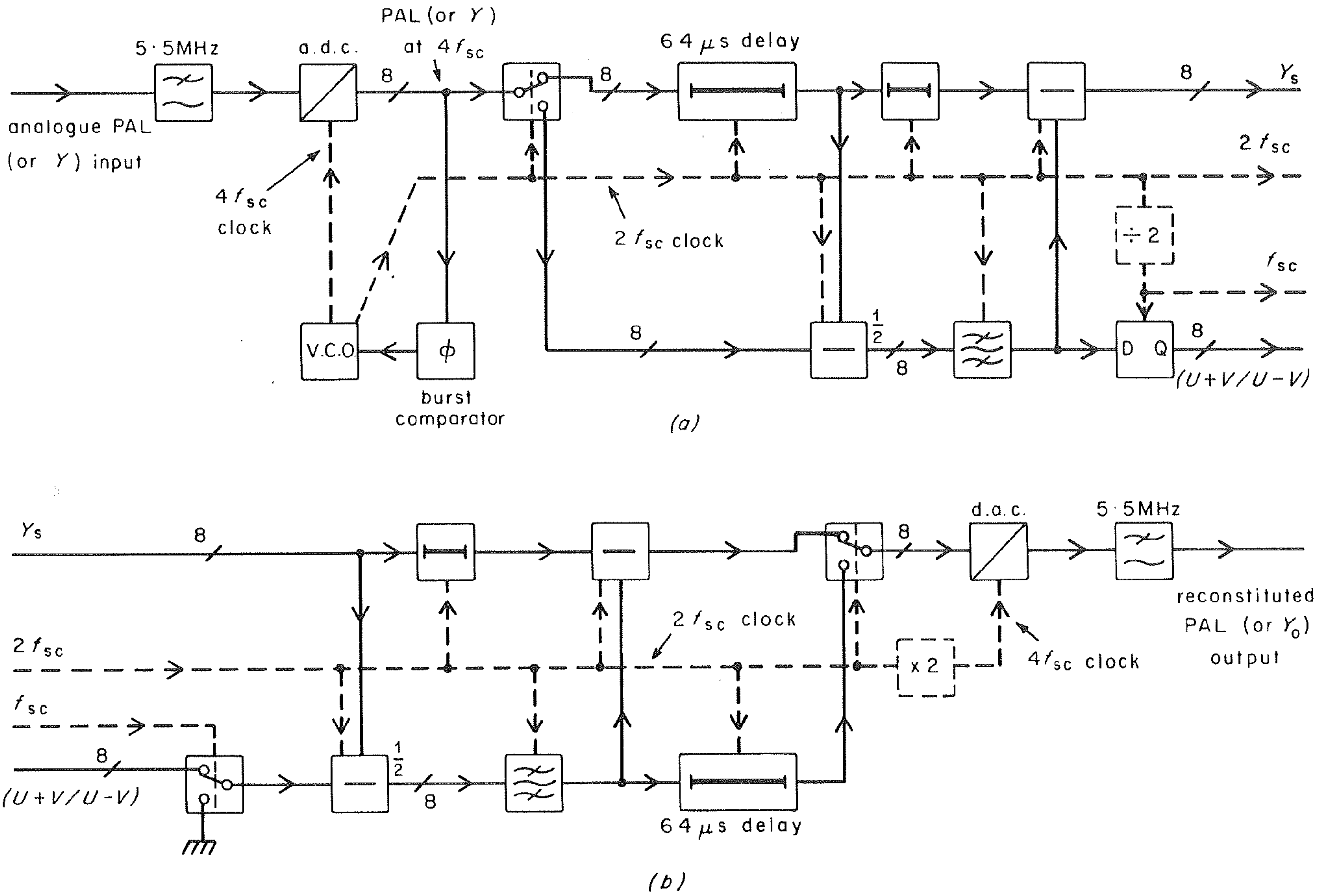

Fig. 10 - Digital comb-filters

(*a*) a.d.c. and input filter (*b*) output filters and d.a.c.

The 4 f_{sc} signal from the a.d.c. is demultiplexed into two 2 f_{sc} data streams, in anti-phase. One of these data streams is delayed by one line period (64 μs) which brings it into phase with the other data stream. The comb-filters can thus employ digital line delays, subtractors, equalising delays and transversal filters all using the same 2 f_{sc} clock pulses. The output filter produces two 2 f_{sc} data streams which are multiplexed to provide the d.a.c. with a single 4 f_{sc} data stream.

3. Performance with test signals

A pair of digital comb-filters and a chrominance separator have been constructed; these allowed digital Y_s, $(U+V/U-V)$ signals to be obtained from a PAL input. The digital Y_s signal was then passed through an output filter to produce Y_0 which was matrixed with separated U_0 and V_0 signals to give an *R.G.B.* display which may be regarded as 'Y_0 U_0 V_0 from PAL'. Alternatively the second comb-filter was used to reconstitute the PAL signal.

3.1. Colour bars

The PAL to Y_0, U_0, V_0 processing removed subcarrier patterning more effectively and over a wider frequency band than the luminance notch in a conventional decoder. Y_0 U_0 V_0 from PAL was almost completely free of plain-area subcarrier patterning and showed far fewer unwanted effects on the transitions of conventional (vertical) colour bars.

Subcarrier patterning was, however, present at the transitions of horizontal colour bars; this patterning varies from field to field and, when partially rectified by the display tube, produced a 12½ Hz luminance flicker.

Cross-talk between U and V also produced a 12½ Hz chrominance flicker at horizontal colour-bar transitions, as predicted in Section 2.2 and illustrated in Fig. 4(*b*); however, this chrominance flicker was less noticeable than the luminance flicker mentioned above.

Horizontal colour-bar chrominance transitions also showed only a slight loss of resolution as compared with those obtained using a conventional delay-line PAL decoder.

None of the effects described above occurred with reconstituted PAL (i.e. PAL produced from Y_s and $(U+V/U-V)$ derived from PAL). The only difference between the pictures given by this form of PAL and the input PAL was a slight chrominance ring on the green/magenta transition of vertical colour bars. This was probably due to the sharp cut 5·5 MHz low-pass filters used in the digital system.

3.2. Test card

Vertical resolution bars are not attenuated, nor do they produce cross-colour (because they are harmonics of the line frequency). Y_0 U_0 V_0 from PAL was thus cleaner and apparently sharper than conventionally decoded PAL. The picture given by reconstituted PAL was indistinguishable from that provided by the input PAL.

3.3. Zone plate

The zone plate is, in effect, a full two-dimensional frequency sweep. This showed that the improved reproduction given by Y_0 U_0 V_0 from PAL on vertical resolution bars (which are described by harmonics of the line frequency) is obtained at the expense of the complete suppression of some diagonal patterns (represented by odd harmonics of half the line frequency) in the chrominance band. These components also gave rise to slightly more cross-colour than with a conventional PAL decoder.

The Y_0 signal contained residual alias components (at odd harmonics of quarter the line frequency) but, in a colour display, these were obscured by the PAL cross-colour components.

Reconstituted PAL was almost identical to unprocessed PAL. There was only a slight residue of the above mentioned effects in the region of 3·4 MHz (as expected from Section 2.5).

4. Subjective tests

4.1. Equipment

Fig. 11 shows the experimental arrangement used. Composite PAL colour signals were obtained from a flying-spot 35 mm slide scanner (with logarithmic masking) and from first generation quadruplex video tape (to provide moving pictures). Monochrome versions of the five slides used, and a still from the (45 second) video tape sequence, are shown in Fig. 12.

The PAL signals were converted to the Y_s, $(U+V/U-V)$ form in a digital comb-filter, after analogue-to-digital conversion at 4 f_{sc}. A second digital comb-filter was used either to reconstruct the PAL signal or to perform output filtering of the luminance (Y_s) signal to provide Y_0. A digital chrominance separator produced separate U_0 and V_0 signals which were matrixed with Y_0 to give R, G and B signals for display.

Two high-quality conventional PAL decoders were used to decode the reconstituted PAL and the input PAL. True RGB signals, and a true luminance (Y) signal, obtained by matrixing the RGB signals, were also available from the slide scanner.

A multiway source-selector enabled the various[*] signals to be displayed on a pair of high-quality picture monitors. Two 22" shadow mask colour monitors were used for the colour tests and two 19" monochrome monitors for the monochrome tests. The peak brightness of the monitors was adjusted to be 70 cd/m^2 (20 ft lamberts); the ambient illumination reflected from the screens was less than 1 cd/m^2.

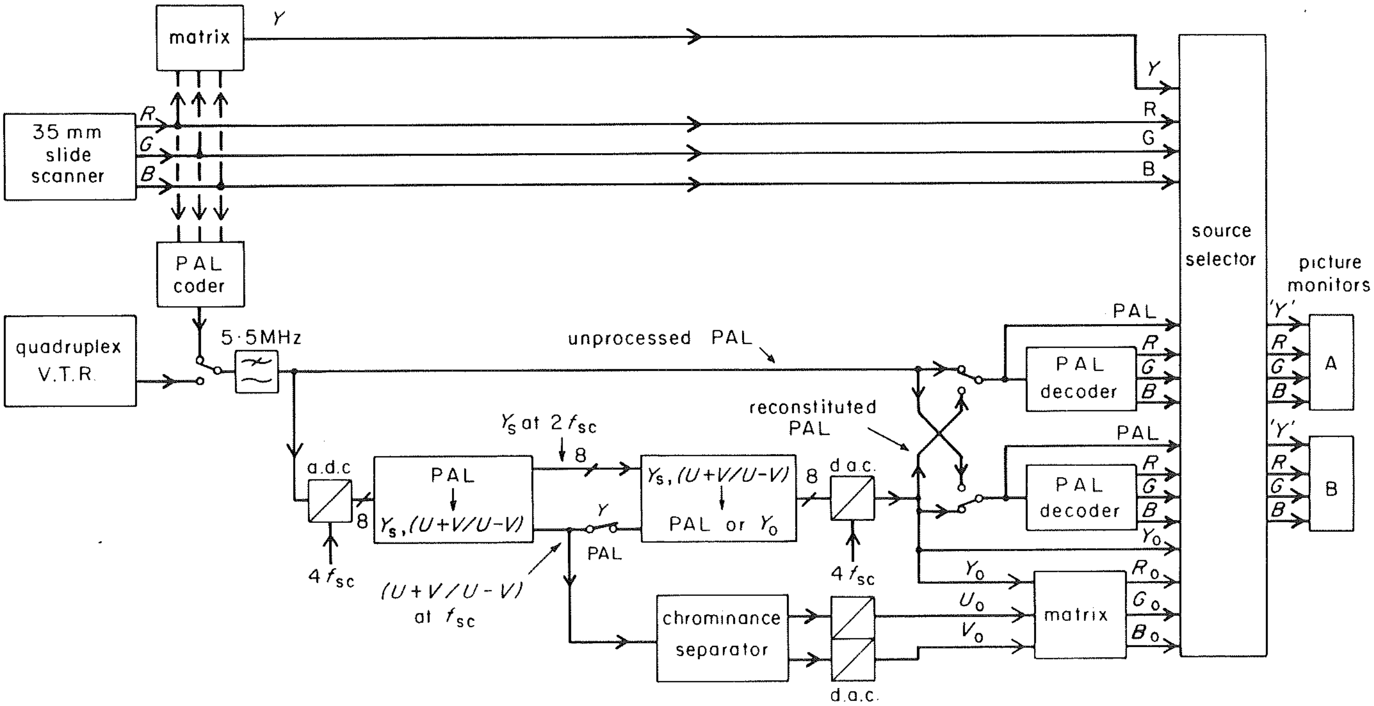

Fig. 11 — Test equipment — block diagram

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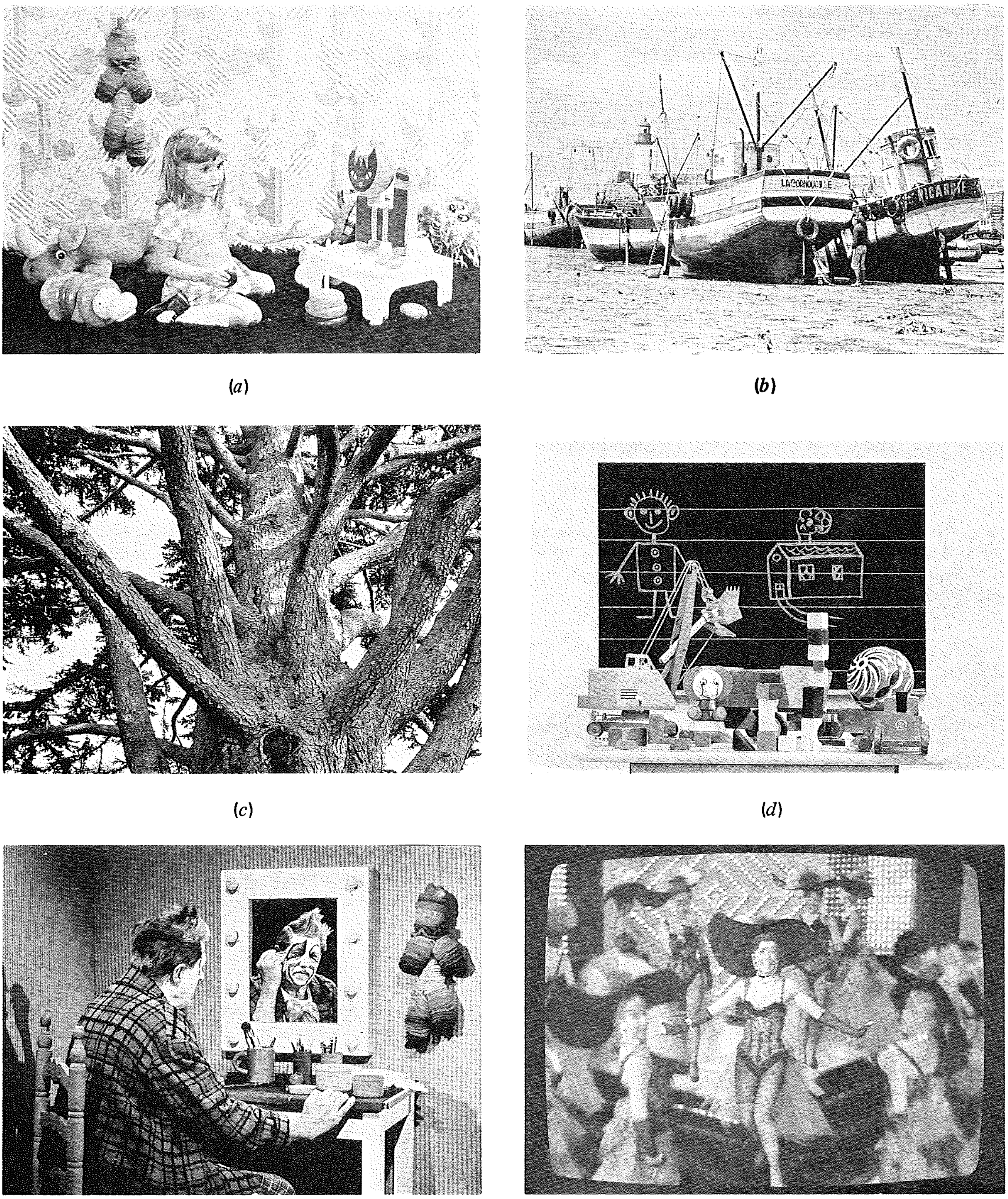
[*] It was not, however, possible to assess Y_0 U_0 V_0 from PAL and reconstituted PAL at the same time.



(*a*) (*b*) (*c*) (*d*) (*e*) (*f*)

Fig. 12 - Test pictures — monochrome versions

(*a*) Girl (*b*) Boat (*c*) Tree (*d*) Blackboard (*e*) Clown (*f*) VTR

4.2. Test procedure

A total of 10 expert observers took part in the tests in 2 groups of 5. 3 were seated at five-times picture height (and asked not to lean forward). The other 2 were seated at seven-times picture height (and allowed to lean forward if they wished).

In each test session the observers were shown about 40 pairs of test pictures, each pair of pictures being displayed for 20 secs. They were asked either to grade each picture separately using the 5-point quality scale or (in separate sessions) to compare the two pictures using the 7-point comparison scale.

Quality Scale

Grade	
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

Comparison Scale

Grade	
+3	Much better
+2	Better
+1	Slightly better
0	The same
−1	Slightly worse
−2	Worse
−3	Much worse

For each slide, pictures according to the following pairs of test conditions were shown, and in order to offset differences between the two monitors the pictures were exchanged between them.

Colour Tests

Absolute assessments		Comparisons		
Reconstituted PAL;	Analogue PAL	Reconstituted PAL	vs	Analogue PAL*
$Y_0\ U_0\ V_0$ from PAL;	Analogue PAL	$Y_0\ U_0\ V_0$ from PAL	vs	Analogue PAL*
$Y_0\ U_0\ V_0$ from PAL;	R, G, B			
Reconstituted PAL;	R, G, B			

Monochrome Tests

Absolute assessments		Comparisons		
Reconstituted PAL;	Analogue PAL	Reconstituted PAL	vs	Analogue PAL*
Y_0 only from PAL;	Analogue PAL	Y_0 only from PAL	vs	Analogue PAL*
Y_0 only from PAL;	Luminance (Y)	Y_0 only from PAL	vs	Luminance (Y)
Reconstituted PAL;	Luminance (Y)			

The tests were carried out in a fairly random order with no slide being used twice in succession. The comparisons marked * were also performed using VTR pictures.

4.3. Results

The tables give the averaged results (for each slide) of 40 absolute assessments and of 20 assessments of each comparison. Each of the VTR results is the average of 40 comparisons.

4.3.1. Colour

Section 2.5 predicts that there should be virtually no difference between reconstituted PAL and the original analogue PAL input. The tests show a very small (but consistent) difference (0·13 of a grade in the absolute tests; 0·2 of a grade in the comparative tests). This is probably due more to quantisation and rounding errors in the digital system than to any fundamental lack of reversibility. Devereux[3] found that 8 bit quantisation of PAL at $3\,f_{sc}$ worsened the pictures by ≃0·2 grade (on the six-point impairment scale).

On most pictures there was little significant difference between $Y_0\ U_0\ V_0$ from PAL and reconstituted PAL (both having suffered similar quantisation and rounding effects).

Slide (c), however, caused $Y_0\ U_0\ V_0$ from PAL to be slightly worse than reconstituted PAL (0·38 of an absolute grade; 1·05 of a comparative grade). Close study of this slide shows that this is because cross-colour patterning (although no greater) is made more visible by an increased tendency for it to crawl predominantly downwards; the PAL to $Y_0\ U_0\ V_0$ process generated cross-colour preferentially from luminance components at odd harmonics of half the line frequency and the patterns generated from these components all appear to crawl downwards.

4.3.2. Monochrome

Here again the effects of quantisation and rounding were noticed in the absolute tests on reconstituted PAL (although in this case they were not confirmed by the direct comparisons).

Despite these effects the comparative freedom from subcarrier patterning caused the Y_0 obtained from PAL to be rated 0·9 of a grade better than PAL itself, and only 0·23 of a grade worse than Y in the comparative tests. In the absolute tests the grade differences were 0·28 and 0·44

5. Conclusions

Either a PAL signal or a YUV separate-component signal may be processed to provide a two-part signal Y_s, $(U{+}V/U{-}V)$.

Y_s and $(U{+}V/U{-}V)$ may be used to derive $Y_0\ U_0\ V_0$ signals that may be used as a substitute for Y, U and V.

TABLE 1

Colour Results

Test / Slide	*RGB*	PAL	Reconstituted PAL	$Y_o\ U_o\ V_o$ from PAL	$Y_o\ U_o\ V_o$ from PAL vs PAL	Reconstituted PAL vs PAL
(a) Girl	4·55	4·32	4·26	4·15	–0·80	–0·40
(b) Boat	4·59	4·40	4·22	4·12	–0·35	–0·30
(c) Tree	4·61	3·43	3·08	2·70	–1·30	–0·25
(d) Blackboard	4·74	3·93	4·00	4·06	+0·13	0·00
(e) Clown	4·61	4·35	4·25	4·18	–0·45	–0·42
(f) VTR	–	–	–	–	–0·04	+0·09
Mean	4·62	4·09	3·96	3·84	–0·47	–0·21

TABLE 2

Monochrome Results

Test / Slide	Y	PAL	Reconstituted PAL	Y_o from PAL	Y_o from PAL vs PAL.	Reconstituted PAL vs PAL	Y_o from PAL vs Y
(a) Girl	4·69	3·93	3·71	4·21	+1·10	+0·13	–0·25
(b) Boat	4·65	4·01	3·73	4·19	+0·88	–0·08	–0·20
(c) Tree	4·55	4·28	3·88	4·08	+0·02	–0·13	–0·40
(d) Blackboard	4·69	3·81	3·70	4·15	+1·60	+0·13	–0·25
(e) Clown	4·76	3·74	3·65	4·51	+0·85	–0·13	–0·03
(f) VTR	–	–	–	–	+0·83	+0·06	–
Mean	4·67	3·95	3·73	4·23	+0·88	0·00	–0·23

When derived from PAL, Y_s and $(U+V/U-V)$ may also be recombined to provide a PAL signal that is almost indistinguishable from the original PAL signal.

6. References

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SECAM Subjective Tests

Since writing the main part of this Report limited tests have been carried out to compare SECAM, produced by direct analogue coding of $R\ G\ B$ and SECAM produced by coding $Y_0\ U_0\ V_0$ derived from PAL. In this case an additional subcarrier notch was included in the Y_0 signal to remove residual PAL subcarrier present on sharp chrominance transitions in the vertical direction.

In order to provide controls for these tests, conventionally coded and decoded PAL and uncoded $R\ G B$ were included in the assessments.

Similar tests to those described in Section 4 were performed using the same slides, but with only one group of four expert observers. Tables 3 and 4 show the results.

The colour results may be regarded as reasonably reliable since the assessments of PAL and $R\ G\ B$ are very similar to those shown in Section 4.3 of the Report. The conclusions to be drawn are that the SECAM colour picture derived from $Y_0\ U_0\ V_0$ is only 0·21 of a grade less satisfactory than directly coded SECAM when assessed on the 5 point quality scale, or 0·35 of a grade less satisfactory on the comparison scale.

The monochrome tests again included an assessment of PAL, and a Y signal derived by matrixing the $R\ G B$ input signals. The assessments of the Y signal agree well with the earlier results in Section 4.3 of the Report. The PAL assessments agree less well, and indicate that these brief tests with four observers should only be regarded as a reasonable indication of picture quality. The tests show that the SECAM picture, derived from $Y_0\ U_0\ V_0$ is 0·35 of a grade less satisfactory than directly coded SECAM on the 5 point scale, or 0·33 of a grade less satisfactory on the comparison scale.

TABLE 3 - Colour Results

Test Slide	RGB	PAL	SECAM	PAL ↓ $Y_0\ U_0\ V_0$ ↓ SECAM	PAL ↓ $Y_0\ U_0\ V_0$ ↓ SECAM vs SECAM
(a) Girl	4·63	4·09	4·0	3·78	–0·38
(b) Boats	4·50	4·31	4·13	4·19	–0·38
(c) Tree	4·63	3·78	3·69	3·38	–0·75
(d) Blackboard	4·66	3·95	4·19	3·66	–0·25
(e) Clown	4·56	4·19	4·19	4·16	0·0
Mean	4·60	4·07	4·04	3·83	–0·35

4 Observers*

TABLE 4 - Monochrome Results

Test Slide	Y	PAL	SECAM	PAL ↓ $Y_0\ U_0\ V_0$ ↓ SECAM	PAL ↓ $Y_0\ U_0\ V_0$ ↓ SECAM vs SECAM
(a) Girl	4·13	2·83	3·38	2·90	–0·63
(b) Boats	4·49	3·37	3·54	3·19	–1·00
(c) Tree	4·34	4·39	3·88	3·51	–0·38
(d) Blackboard	4·59	2·43	2·99	2·91	–0·38
(e) Clown	4·44	2·75	3·35	2·89	0·0
Mean	4·40	3·15	3·43	3·08	–0·33